

Evaluation of MgB₂ for Future Accelerator Cavities

Proposal for LCRD/UCLC 2005

Classification (subsystem)

RF Cavity in main linac

Personnel and Institutions requesting funding

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Collaborators

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Project Leader

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Introduction

Superconducting RF technology was chosen for the International Linear Collider (ILC) in August 2004. While Nb technology is the baseline for the ILC design and associated R&D should be the first priority, it is still important to find a new superconducting material that can exceed the Nb performance.

Since the accelerating gradient (E_{acc}) of Nb cavities are theoretically limited at ~50 MV/m, finding a material that can exceed this limit would open up the possibility of increasing the achievable E_{acc} , leading to a shorter and more cost effective accelerator.

A material such as magnesium diboride (MgB₂), that has a higher superconducting transition temperature ($T_c=39$ K) than Nb ($T_c=9.2$ K), could not only provide a higher gradient but also give other benefits, such as a higher cavity Q_0 at the same operating temperature and increasing the quench margin due to the higher T_c . If the ILC can be operated with lower losses or at a temperature higher than 2 K, the capital and operational costs for the cryogenic system could be significantly lower.

Motivation

Superconductivity in the intermetallic compound MgB₂ was recently discovered with the T_c as high as 39 K (Nagamatsu et al., 2001). Although its T_c is not as high as of so-called high- T_c materials such as YBCO, its metallic nature and the ensuing simplifications in fabrication have triggered a number of studies.

Regarding the application to RF cavities, Collings et al. show the potential of MgB₂ having a ~50 % higher theoretical critical magnetic field than Nb [1]. Tajima proposed a method to form a bulk MgB₂ layer inside a copper cavity using a hot isostatic press (HIP)

technique [2]. In the field of MgB_2 fabrication, Nesterenko et al. have successfully developed a method to fabricate a dense MgB_2 using an ordinary HIP machine [3]. Fully dense material with a mirror-like surface quality is important for microwave devices such as RF cavities and for enabling fabrication of superconductor thin films with superior quality via laser ablation and sputter deposition.

The most important feature for a radio-frequency (RF) cavity for particle accelerators is RF loss at high surface magnetic fields. Unfortunately, oxide-based high- T_c materials such as YBCO show rapid increase of RF surface resistance (R_s) with higher magnetic fields and cannot be applied to RF cavities. MgB_2 , however, has shown much less increase of R_s with higher magnetic fields [4]. For example, Figure 1 shows a recent result of the dependence of RF surface resistance (R_s) on the surface magnetic field [5]. As one can see, the R_s did not increase up to 60 Oe and showed small increase at ~ 120 Oe. These numbers are equivalent to $E_{\text{acc}} \sim 1.5$ and 3 MV/m, respectively. In the experiment, the highest available field was limited by the available power.

Although the sample used in this experiment showed higher R_s than Nb, possibly because the film was not optimized, some good films have already shown lower R_s at 4 K. Figure 2 shows such an example. It indicates that further reduction is possible by reducing the residual resistance.

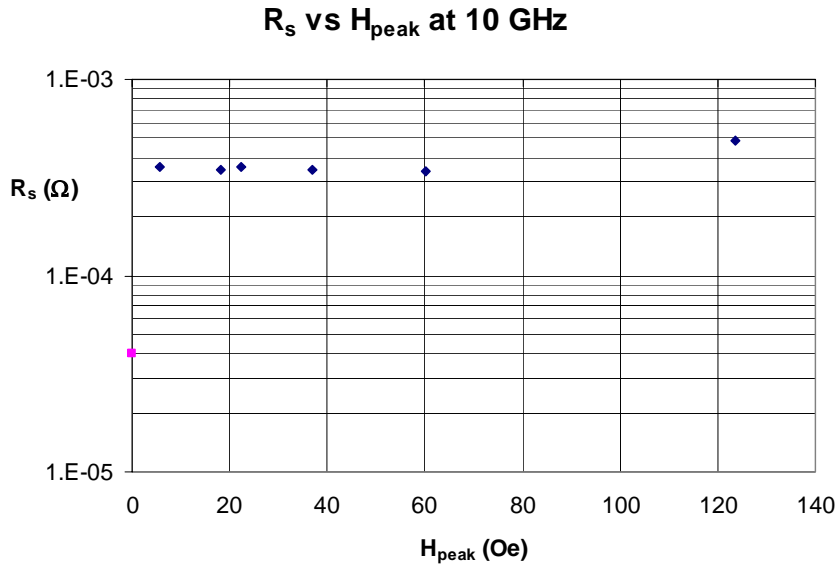


Figure 1: R_s dependence on surface magnetic field [5]. The purple dot shows the BCS resistance of Nb as a reference.

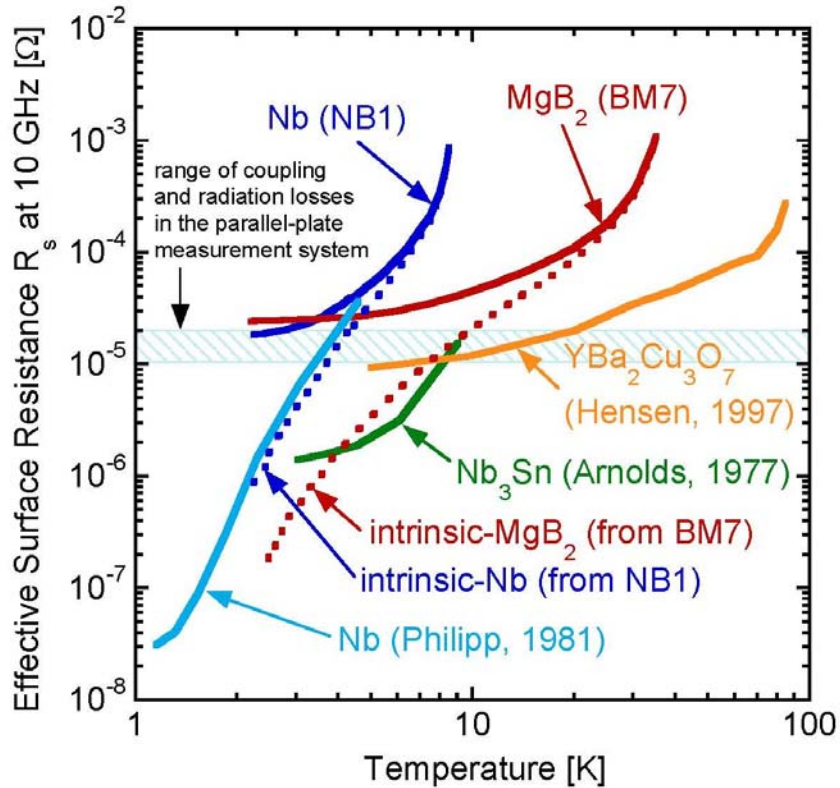


Figure 2: RF surface resistance of MgB_2 film measured at LANL a function of temperature. As a reference, Nb data are shown. Also, dotted lines are the prediction without residual resistance [6].

With much higher T_c of 39 K compared to 9.2 K for Nb, it is worthwhile to investigate the possibility of using this material for an RF cavity.

Capability of studying MgB_2 at UCSD

UCSD has unique expertise in hot isostatic pressing (HIPing) of magnesium diboride (bulk and wire) with excellent mechanical and superconducting properties [3, 7-17]. The PI laboratory has full scale processing equipment based on cold and hot isostatic presses and all steps starting with vacuum encapsulation are performed in house.

The UCSD team also has the expertise and equipment for the application of the Resonant Ultrasound Spectroscopy (RUS) method [18] for high accuracy measurements of elastic properties of magnesium diboride which can be used for tuning of the HIPing. The first published data on elastic properties of HIPed solid magnesium diboride are in good agreement with theoretical estimates. We plan to use RUS measurements of elastic moduli as a very accurate method to control the material quality. Another application of the RUS measurements will be the evaluation of elastic moduli of composite materials (such as the composite-structured, MgB_2 with improved surface resistance) and the quality of bonding between components based on measurements of Q .

Capability of testing MgB₂ samples and cavities at LANL

The SRF Structures Lab at Los Alamos Neutron Science Center (LANSCE) has a capability of measuring MgB₂ samples [19] and SRF cavities [20]. It has 200-600 Watt RF amplifiers from 0.2 – 4.0 GHz. Also, it has a number of 3-GHz Nb single-cell cavities on which a MgB₂ film can be coated as soon as a reasonable coating technique has been developed.

Project Overview

UCSD and LANL have agreed to collaborate on the evaluation of MgB₂ for the application to the RF cavities. According to the agreement, UCSD will be responsible for providing the samples of bulk magnesium diboride and possibly high-quality MgB₂ targets for the development of laser vapor deposition and/or magnetron sputtering techniques. LANL will be responsible for measuring the RF properties such as surface resistance, its field dependence and the critical magnetic field. Both parties are responsible for developing the techniques to fabricate MgB₂ cavities and will share the efforts related to analysis and publication.

The following project goals have been defined:

- 1) Establish the fabrication parameters to get an RF surface resistance lower than Nb at 4 K for bulk and film MgB₂.
- 2) Develop one or more technique(s) to deposit a high-quality MgB₂ film on the inner surface of a cavity made of Nb and/or Cu.
- 3) Develop one or more technique(s) to make a cavity with a high-quality bulk MgB₂.
- 4) Measure Q₀ versus E_{acc} curves of the cavities made of film MgB₂ and bulk MgB₂ to compare with Nb results.
- 5) Test critical magnetic field to compare the theoretical limits with Nb.

Broader Impact

The outcome of the proposed work will broadly contribute to the advancement of understanding of the relationship between processing, microstructure/defects, and superconducting microwave properties of MgB₂. Successful fabrication of fully dense superconductors and high-quality films in practical configurations, such as microwave cavity components, will have major impacts on applications of superconductors for communications and energy applications. Graduate students involved in this research will be educated and trained in the materials science of superconductors as well as in the forefront aspects of superconductor microstructural control, properties and applications. The outcome of this exciting superconductor materials/technologies research will broadly benefit the superconductor industries as well as stimulate research and development effort in academia and research institutes.

Project Activities and Deliverables

During FY05, we plan to complete the optimization of the MgB₂ fabrication technique to lower the residual resistance so that the RF surface resistance is reduced to less than that of Nb at 4 K. We also plan to complete fabrication of the targets to be used for laser ablation or magnetron sputter coating of MgB₂. In addition, we plan to measure the critical magnetic field using small samples.

During FY06, we plan to develop a method to fabricate a bulk MgB₂ cavity using a CIP/HIP technique. Also, in collaboration with other labs, we plan to develop a method to coat the inner surface of a cavity. Since there are 3-GHz Nb cavities at LANL, we will try to coat those cavities first, but our ultimate goal is to coat on a highly-thermal conductive metal such as copper. We also plan to complete the critical magnetic field measurement.

During FY07, we plan to demonstrate at least one method to either fabricate a bulk MgB₂ cavity or to coat MgB₂ on a Nb or copper cavity and measure the Q₀ versus E_{acc} curve.

Budget Justification

The budget request includes funding for salary of a graduate student, who will dedicate 6 months per year to this effort (including travel to meetings/conferences). Also included are some upgrades of the equipment for fabricating MgB₂ samples and its supplies at UCSD and costs for testing the samples at LANL. The following budgetary estimate is in k\$.

Table 1: Budgetary estimate (in k\$) for UCSD-LANL collaboration on the evaluation of MgB₂ for SRF cavities.

Item	FY 2005	FY2006	FY2007
Graduate student salary (6 months)	10.0	10.0	10.0
0.5 month PI summer salary (including academic summer salary benefits)	7.0	7.0	7.0
Total Salaries (incl. fringe benefits)	17.4	17.4	17.4
Travel	2.0	2.0	2.0
Materials and Supplies	4.0	4.0	4.0
Samples preparation	5.0	5.0	5.0
Tests at LANL	10.0	10.0	10.0
Total direct costs	38.4	38.4	38.4
Total indirect costs (incl. 54%)	20.7	20.7	20.7
Total direct and indirect costs	59.3	59.3	59.3

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PERSONAL: Date of birth: January 16, 1949, Russia; U.S. Citizen.

EDUCATION:

- 1971 - Diploma with Excellence, Department of Physics, NSU, Novosibirsk, Russia.
- 1975 - Ph.D. in Physics, Academy of Sciences, Russia
- 1989 - Doctor of Physics and Mathematics, Academy of Sciences, Russia.

EXPERIENCES (last 10 years):

- March 1996 – Present Professor of Materials Science, University of California, San Diego.
- October 1999 - January 2003 Director of UCSD Materials Science and Engineering Program.
- March 1994 - March 1996 Visiting Scholar, Dept of Applied Mech. and Eng. Sciences, UCSD

5 PUBLICATIONS (most closely related to the proposed project)

- S.S. Indrakanti, V.F. Nesterenko, M.B. Maple, N.A. Frederick, W.M. Yuhaz, and Shi Li, Hot Isostatic Pressing of Bulk Magnesium Diboride: Mechanical and Superconducting Properties, *Phil. Mag. Lett.*, **81**, 849-857, 2001.
- N.A. Frederick, Shi Li, M.B. Maple, V.F. Nesterenko, and S.S. Indrakanti, Improved Superconducting Properties of MgB₂, *Physica C*, **363**, 1-5, 2001.
- A.T. Findikoglu, A.Serquis, L. Civale, X.Z. Liao, Y.T. Zhu, M. Hawley, F.M. Muller, V.F. Nesterenko, and Y. Gu “Microwave Performance of Fully-Dense Bulk MgB₂”, *Appl. Physics Lett.*, **83**, 108-110, 2003.
- A.Serquis, L. Civale, D.L. Hammon, X.Z. Liao, J.Y. Coulter, Y.T. Zhu, M. Jaime, D.E. Peterson, F.M. Muller, V.F. Nesterenko, and Y. Gu, “Hot Isostatic Pressing of Powder in Tube MgB₂ Wires”, *Appl. Phys. Lett.*, **82**, 2847-2849, 2003.
- V.F. Nesterenko and Y. Gu “Elastic Properties of Hot Isostatically Pressed Magnesium Diboride”, *Appl. Phys. Lett.*, **82**, 4104-4106., 2003

5 OTHER SIGNIFICANT PUBLICATIONS

- A. Serquis, X.Y.Liao, Y.T. Zhu, J.Y. Coulter, J.Y. Huang, J. O. Willis, D.E. Peterson, F.M. Mueller, N.O. Moreno, J.D. Thompson, V.F. Nesterenko, and S.S. Indrakanti, Influence of Microstructures and Crystalline Defects on the Superconductivity of MgB₂, *Journal Applied Physics*, **92**, 351-356, 2002.
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 - V.F. Nesterenko, W. Goldsmith, S.S. Indrakanti, and Yabei Gu, Response of Hot Isostatically Pressed Ti-6Al-4V Targets to Normal Impact by Conical and Blunt Projectiles, *Int. .J. of Impact Eng.*, **28/2**, 137-160, 2003.
 - C. Daraio, V.F. Nesterenko and S. Jin “Highly Nonlinear Contact Interaction and Dynamic Energy Dissipation by Forest of Carbon Nanotubes”, *Appl. Phys. Letters*, **85**, 5724-5726, 2004.
 - V.F. Nesterenko, Dynamics of Heterogeneous Materials, Springer-Verlag, NY, 2001.
- Total number of publications in Archival Journals 107, two books.

RESEARCH INTERESTS

- High pressure, high temperature powder-based processing of advanced materials (magnesium diboride, titanium alloy based materials, wafer bonding)
- Strongly nonlinear wave dynamics in phononic metamaterials
- Dynamic behavior of materials
- Research supported by NSF, ONR, LANL, SRI, and von Liebig foundation.

AWARDS AND HONORS: Fellow of American Physical Society